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IN RE APPLICATION OF: Christopher John Howard WORT, et al.

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FOR: HEAT SPREADER

**REQUEST FOR PRIORITY UNDER 35 U.S.C. 119
AND THE INTERNATIONAL CONVENTION**Commissioner for Patents
Alexandria, Virginia 22313

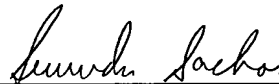
Sir:

In the matter of the above-identified application for patent, notice is hereby given that the applicant claims as priority:

| <u>COUNTRY</u> | <u>APPLICATION NO</u> | <u>DAY/MONTH/YEAR</u> |
|-----------------------|------------------------------|------------------------------|
| Great Britain | 0223321.1 | 08 October 2002 |

Certified copies of the corresponding Convention application(s) were submitted to the International Bureau in PCT Application No. PCT/IB03/04420.

Respectfully submitted,
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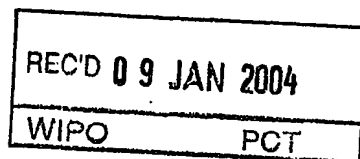


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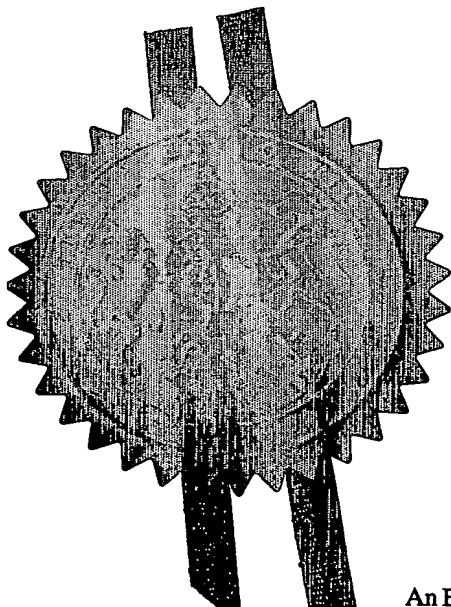
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09OCT02 E754142-1 D00059
P01/7700 0.00-0223321.1

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| 1. Your reference | PA134041/P | | |
| 2. Patent application number (The Patent Office will fill in this part) | 08 OCT 2002 | 0223321.1 | |
| 3. Full name, address and postcode of the or of each applicant (<i>underline all surnames</i>) | Element Six Limited Isle of Man Freeport Ballasalla Isle of Man IM99 6AQ | | |
| 08479958001 Patents ADP number (<i>if you know it</i>) | | | |
| If the applicant is a corporate body, give the country/state of its incorporation | Isle of Man, U.K. | | |
| 4. Title of the invention | HEAT SPREADER | | |
| 5. Name of your agent (<i>if you have one</i>) | Carpmaels & Ransford | | |
| "Address for service" in the United Kingdom to which all correspondence should be sent (<i>including the postcode</i>) | 43 Bloomsbury Square London WC1A 2RA | | |
| Patents ADP number (<i>if you know it</i>) | 83001 | | |
| 6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (<i>if you know it</i>) the or each application number | Country | Priority application number (<i>if you know it</i>) | Date of filing (<i>day / month / year</i>) |
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Description 9

Claim(s) 1

Abstract

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11. I/We request the grant of a patent on the basis of this application.

Signature

Date

Carpmaels & Ransford 8th October 2002
Carpmaels & Ransford

12. Name and daytime telephone number of person to contact in the United Kingdom

Mr. A.J. Jones

020-7242 8692

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BACKGROUND OF THE INVENTION

This invention relates to heat spreaders.

Thermal management materials can be divided into two distinct groups. The first is heat sinks and the second is heat spreaders. A heat sink is used to remove heat from an object or closed system, such as is the case with heat transfer into a metal block which then passes the heat into ambient air or a water cooling circuit. A heat spreader, on the other hand, is used to rapidly conduct heat away from a local "hot spot" into the bulk of the heat spreader. The heat spreader is normally in thermal contact with a heat sink for removal of the heat generated entirely from the system.

Heat flow follows the principle of conservation of flux, wherein the total heat flux across any surface enclosing the source is the same. Closer to the heat source the surface area is smaller and thus if the material had uniform thermal conductivity the temperature gradient would be larger. Consequently there is considerable benefit of having a high thermal conductivity heat spreader in that region.

Heat is conducted by two main mechanisms, electronic transfer and lattice vibrations. In most good thermal conductors, the dominant mechanism is electronic transfer, where hot electrons are free to disperse and carry heat with them. The movement of these electrons also makes these materials good electrical conductors. In a more limited group of materials, the thermal conduction arises from phonon transfer in the lattice, and these materials can be electrical insulators.

Heat sinks are thus often metallic in nature and electrically conducting. As they are used to remove heat from a relatively large surface area, the power density is low and thus the thermal conductivity of many metals, for example aluminium or copper, is acceptable.

Heat spreaders, on the other hand, rely totally on their ability to remove heat from local "hot spots" and their thermal conductivity is vitally important. Materials such as Si, SiC, Cu, Al and Ag are good heat spreaders in their own right, and in many cases can be fabricated into even better heat-spreaders when the bulk material is loaded with diamond crystals thus forming a composite material. By varying the diamond proportion in the composite both the thermal conductivity and the average thermal expansion coefficient can be tailored to the application. However all these materials electrically conduct, at least to some degree, even in the form of a diamond loaded composite, and this limits their application.

Diamond, and in particular CVD diamond, is extremely attractive as a heat spreader. Diamond has a very stiff, rigid lattice and a very wide band gap, resulting in excellent thermal conduction by phonon transfer and extremely good electrical insulation. However, heat spreaders are required in applications which are very price sensitive, and often solid diamond layers cannot be produced at the required cost.

Other materials which are also electrically insulating and which can be used as heat spreaders are alumina, beryllia, aluminium nitride and boron nitride. However, compared to diamond these materials have a much lower thermal conductivity, and a significantly lower thermal conductivity than the better diamond loaded composite materials described earlier.

SUMMARY OF THE INVENTION

According to the present invention, a heat spreader, particularly for an electronic device, comprises a layer of CVD diamond grown onto a diamond loaded material comprising a mass of diamond particles in a matrix, wherein the layer of diamond is bonded to the exposed diamond particles of the diamond loaded material at least in part by epitaxy. The diamond loaded material will hereafter be referred to as "DL material".

Preferably, the bonding by epitaxy between the layer of diamond and the diamond particles of the DL material is deliberately enhanced over that which might occur naturally using untreated DL material.

The DL material will generally be provided in the form of a layer with the layer of diamond being produced on the surface of the layer of DL material.

According to a further aspect of the invention, a heat spreader comprises a layer of DL material having major surfaces on each of opposite sides thereof, and a layer of diamond in thermal contact with each of the major surfaces, with either one or both of the diamond layers being bonded at least in part by epitaxy to exposed diamond particles of the DL material, and preferably where this bonding by epitaxy between the layer of diamond and the diamond particles of the diamond loaded material is deliberately enhanced over that which might occur naturally using untreated DL material.

A further aspect of the invention is the use of surface preparation techniques and growth conditions for the growth of the CVD diamond layer such as to optimise the bonding by epitaxy between the CVD diamond layer and the diamond loading of the DL material.

DESCRIPTION OF EMBODIMENTS

The DL material can be any diamond loaded material, for example diamond loaded material where the matrix is Si, SiC, Cu, Al or Ag. Preferably, the matrix of the DL material is one of Si and SiC, and more preferably is SiC. The preferred matrix may be application specific, choosing a particular matrix with specific diamond loading to match the thermal expansion coefficient of the Si based devices that will be attached to the heat spreader. In this instance, the matrix may itself have a thermal expansion coefficient close to or larger than that of the Si devices, and the diamond loading selected to reduce the composite thermal expansion coefficient to suit. Preferably the diamond particles loading the material are greater than 10 μm in diameter, and are preferably synthetic Ib or natural IIa diamond. A mixture of diamond particle sizes is preferably used to ensure good loading of the DL material, although the precise size distribution can be tailored for the application.

The invention is particularly beneficial where the DL material provides a relatively high thermal conductivity, but insufficient electrical isolation on its own. The CVD diamond layer bonded to the surface of the DL material then provides the electrical isolation, and its thickness is chosen to provide the isolation characteristics (voltage, leakage current) required by the application. Additionally, the diamond provides a surface which is much more easily planarised or provided with a high surface finish than that of the underlying diamond loaded material and can therefore be made more suitable for metallisation, photolithography and mounting of devices.

Typical thicknesses of the diamond layer are 0.1 μm – 300 μm , and preferably 1 μm -200 μm , and more preferably 2 μm – 150 μm and even more preferably 10 μm – 100 μm .

A problem with using multiple layers in heat spreaders, however, is the thermal impedance of the boundaries. This thermal impedance may arise as a result of degraded material at the boundaries, poor mechanical

contact, phonon scattering due to thermal mismatch at the boundaries, and the like. Accordingly, in order to address this problem, this invention provides that when CVD diamond is synthesised onto a DL material, the preparation and growth conditions are chosen to enable or enhance the ability of the diamond to grow epitaxially on the diamond crystals present or exposed at the surface of the DL material. Elsewhere, such as between the diamond crystallites at the DL material surface, the diamond layer will nucleate as typical fine grain polycrystalline diamond. This epitaxial growth of the CVD diamond layer onto the diamond of the DL material forms a very good thermal match to the DL material, avoiding degraded material at the boundary, or poor mechanical contact, or phonon scattering due to poor thermal matching.

It has been found that the very fine grain nucleation layer typical on DL materials that have not been specially prepared has much poorer thermal properties than the larger grain size material which results from epitaxy. This fine grain layer of poorer thermal conductivity can typically be 25 μm or so thick. Consequently the thermal properties of the interface between the diamond and the DL material are further degraded, and the thermal conductivity of the whole thickness of the diamond layer may be degraded, dependent on the thickness used. A further advantage of employing epitaxial growth at the interface is that the diamond layer has in general a substantially larger grain size throughout its thickness than a layer grown up from the very fine nucleation material generally found in normal polycrystalline diamond growth nucleated on the matrix materials of DL materials. As a consequence of the larger grain size throughout its thickness, the thermal properties of the whole CVD diamond layer are improved.

The relative surface area of the DL material which is exposed diamond can be enhanced by a variety of means, as can the method of forming an epitaxial bond between this exposed diamond in the DL material and the CVD diamond layer.

In particular, the epitaxy is preferably enhanced to the point at which one or more of the following is achieved:

1. epitaxial growth by CVD on the diamond loading of the DL material forms a substantial portion of the surface area of the interface between the CVD diamond layer and the DL material, where this substantial portion of the surface area exceeds 10%, or exceeds 20%, or exceeds 30%, or exceeds 40%, or exceeds 50%, or exceeds 60%, or exceeds 70% of the total surface area.
2. CVD diamond grains produced by epitaxial growth on the diamond loading of the DL material form a substantial portion of the surface area of the final growth surface. The lateral dimensions of the CVD diamond grains nucleated on the matrix or otherwise at the interface between the CVD diamond layer and the DL material are generally of the order of the thickness of the layer or less at the growth surface, whereas the lateral dimensions of grains grown epitaxially on the diamond loading of the DL material are generally of the order of the particle size of the diamond loading. Where the CVD diamond layer thickness is substantially smaller, by more than 4 times and preferably by more than 10 times, than the particle size of the diamond loading of the DL material, then an analysis can be made of the grain size distribution at the growth surface. Using a polish and subsequent etch to reveal grain boundaries, the total surface area at the growth surface of grains with one and preferably two lateral dimension exceeding 4 times and more preferably 10 times the diamond layer thickness must cover a substantial portion of the growth surface of the CVD diamond layer when polished, where this substantial portion of the surface area exceeds 10%, or exceeds 20%, or exceeds 30%, or exceeds 40%, or exceeds 50%, or exceeds 60%, or exceeds 70% of the total surface area.
3. the epitaxial diamond grown by CVD on the diamond loading of the DL material forms a substantial portion of the volume of the CVD

diamond layer, where this substantial volume exceeds 10%, or exceeds 20%, or exceeds 30%, or exceeds 40%, or exceeds 50%, or exceeds 60%, or exceeds 70% of the volume of the CVD diamond layer.

For instance embedded diamond crystals can be exposed by lapping the composite material prior to deposition of the CVD diamond layer. This lapping can also be used to planarise the material, although a planar interface is not necessarily the best thermal interface and final planarisation may be better performed after the growth of the diamond layer.

Alternatively, or in addition, the diamond loaded composite material can be a graded material, such that the loading density and particle size distribution at the surface is optimised on the basis of one or more of:

- a) improving the degree of epitaxy between the CVD diamond layer and the diamond of the DL material;
- b) improving the thermal expansion match between the diamond layer and the surface of the DL material,

whilst in the body of the DL material the loading density and particle size distribution may be optimised to other parameters such as bulk thermal conductivity, cost, or matching (both thermal conductivity and thermal expansion coefficient) to the underlying heat sink. The loading particle size distribution may also be optimised according to the intended thickness of the overgrown diamond layer.

As a further alternative, the preparation and growth conditions for the CVD diamond layer can be optimised for the growth of the epitaxial diamond on the diamond loading of the DL material. In particular, a chemical etch or plasma etch may be used to ensure a clean diamond interface for epitaxial growth, and to modify and control the nucleation density and nucleation time of the fine intergranular diamond nucleation. Control of the latter parameters, and of the relative growth rates of the large epitaxial diamond and fine nucleated diamond (for example by using growth parameters) can be used to control the grain structure of the CVD diamond layer. In

addition, the gas composition in the growth process, and in particular the concentration of the carbon source, may be controlled to optimise epitaxy.

A second layer of diamond may be bonded to or grown onto the reverse face of the DL material. This layer may assist in the interface with a subsequent heat sink material. This second layer may also benefit from the range of techniques used to enhance the degree of epitaxy between the diamond layer and the diamond loading of the DL material

Furthermore, the invention also includes the use of a layer of DL material, having major surfaces on opposite sides thereof and a diamond layer in thermal contact with one or both of the major surfaces, for use as a heat spreader material. A particular embodiment is where a device requiring thermal management is mounted or bonded to the outer face of a diamond layer bonded to the DL material using the method of this invention.

The diamond layer in the heat spreader of the invention further provides the heat spreader with sufficient electrical isolation for the mounting of electronic devices, and with a performance as a heat sink which is preferably at least as good as known DL materials and more preferably enhanced over known DL materials.

The diamond layer may be smoothed, planarised or polished and will be in contact with the electronic device or other heat source. The diamond layer may cover an entire surface of the DL material or may cover only specific areas, for example, if the heat spreader is to be used in a multi-chip module.

The DL material will generally be placed in thermal contact with a heat sink such as a metallic heat sink.

The diamond layer and/or the DL material may be metallised or patterned to provide suitable contacts to an electronic device or aid in joining the heat spreader to a heat sink. Holes through the diamond layer and/or DL

material may also be provided for electrical interconnection, optical addressing or other purpose. Where the DL material is coated on both sides with diamond, the conductive DL material may be used as a ground plane, or as one of the electrical interconnects to the devices.

The layer of diamond is preferably a layer of CVD diamond grown on a layer of DL material, which is preferably lapped prior to coating with CVD diamond. Generally, the diamond layer will be thin and typically have a thickness of no more than 300 μm . However, the diamond layer thickness will be chosen to provide suitable electrical isolation between the device and the DL material. For example, to hold off 1000V the diamond layer would need to have a thickness of at least 25 μm . The thickness of the diamond layer will also be chosen to ensure that the overall thermal performance of the heat spreader conforms to requirements whilst remaining cost effective.

The CVD diamond may be produced by known methods and is generally polycrystalline.

The heat spreader of the invention has particular application to large electronic devices such as silicon-based devices. For such large devices, the relatively inexpensive heat spreaders such as aluminium nitride are not suitable because of the difference in thermal expansion coefficient between the silicon-based device and aluminium nitride. Diamond has a much closer match, but diamond on its own for such a device would be expensive. The heat spreader comprising a thin diamond layer in thermal contact with a layer of DL material provides an effective heat spreader and electrical isolation at a commercially competitive price. DL materials alone cannot be used in many applications as they all electrically conduct. The CVD diamond layer provides electrical insulation without impairing the thermal conductivity, and generally increases the thermal conductivity in the layer immediately adjacent to the device to be cooled.

PCT Application

IB0304420

